

Liberties in Nature. On Photons, Bugs and Chess Players

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Abstract

Free will is an old philosophical enigma that has been recently revived by neuropsychology. We restrict ourselves to the problem that determinism seems to allow only an illusion of freedom but random decisions do not contain any freedom either. We show that this is a problem of natural sciences, not philosophy. Physics motivates replacing determinism by the principle of weak causality and introducing the concept of liberty. Its empirical basis remains untouched, but the theoretical interpretations of the state space in Newton theory and of the space-time in general relativity are changed. The emerging understanding of time agrees with the idea suggested once by Popper. In biology, the most important liberties are those of mutation, of motion and of the portable neural representation. We distinguish freedom and liberty. Each freedom is associated with some liberty and is defined as the ability to perform three processes called realization, selection and use of memory. This makes freedom accessible to experimental study. The freedom of will is explained by giving account of the underlying specific liberty and processes. While the realization has an ample space for randomness, the selection is mostly causal. Thus, determinism can be rejected without forcing decisions to be random. The experiments of Libet and the role of consciousness are discussed.

1 Introduction

The interest in the free will has been enhanced today by the progress in neuropsychology. [1]. The old philosophical enigma is concisely described in [2]. One particular problem seems to be the following. If determinism is assumed, then the free will appears to be an illusion: everything is fixed and there seems to be no freedom.¹ On the other hand, if determinism is rejected, then it seems that decisions of the will must be random. Thus, there is no control and this does not look very free either. There are other problems associated with the free will, such as morality etc. We shall ignore these here.

In the present paper, we are going to explain how a solution of the above problem emerges from natural sciences. Physics teaches us how determinism can be abolished and biology shows the way of how decisions of the will then still need not become random. The paper is necessarily a sketch of a research project rather than a complete scientific analysis considering all details and aspects. But we shall try hard to formulate the main ideas as clearly and distinctly as possible and to make them accessible to readers with various backgrounds.

The plan of the paper is as follows. Sec. 2 is dedicated to physics and asks the question which physical phenomena are strictly tied by unique rules and which liberty remains after the physical laws are accepted. We find that the liberty is large even in Newton mechanics: the choice of system and the choice of its initial data are free. We give this liberty a slightly different interpretation than is usually adopted. Then, a short account of quantum mechanics will show that it allows even more liberty and that the additional liberty does not concern exclusively the micro-world. This motivates the formulation of the weak causality principle and the corresponding notion of time on which the conceptual framework of this paper is based (c.f. [4]). This notion of time is not compatible with the usual understanding of general relativity, but a subtle change in the interpretation of spacetime can make the framework logically coherent. This reinterpretation does not influence any observable property.

The examples met in physics motivate the introduction of the central notion of the paper, the liberty, in Sec. 3. A liberty is constituted by alternative possibilities under certain conditions and is experimentally testable.

The final section lists the most important liberties that concern living organisms. It is the liberty of mutation, of motion and of portable neural representative. While the first two are simple and well defined, the last one remains a little obscure as to its actual structure within nervous system. We analyze some experiments by Jim

¹There is a philosophical school called compatibilism trying to define freedom in a way compatible with determinism [3]. It is not satisfactory because the assumption of determinism is not plausible.

Gould to show that *what* is represented as well as the *existence* of such representation by neural structures are clearer. We distinguish liberty and freedom. Liberties can be found even in physics but freedom concerns only the living organisms—even bacteria—, so our language is a little different from the common use. The concept of freedom includes structures and processes in living organisms by means of which they take advantage of liberties. Several freedoms are described and the respective structures are studied. We finish with the freedom of will, which turns out to have the same general structure as all other freedoms. It is understood as a natural phenomenon and given a position in the class of similar phenomena. We specify the role of consciousness in this particular case and use it to give the experiments by Libet a new interpretation.

Two processes underlying any freedom are the realization of the alternatives contained in a liberty and the selection of one from the list of the alternatives. Some kind of memory is always necessary to carry out the two processes; hence use of memory is the third basic process. As a rule, the realization contains a lot of randomness while the selection is mostly causal. This is possible because the weak causality principle does not abolish the causality wholesale.

To prove that the determinism is wrong does not belong to the aims of the present paper. We just accept that it has become very unpalatable after eighty years of quantum mechanics. Everything we do is to *assume* that the determinism is false and that the weak causality principle is true. Then, we shall check the self-consistence of the new framework, see if the validity of the principle and the existence of specific liberties are compatible with the contemporary empirical knowledge as well as find the new theoretical ordering and understanding of this knowledge provided by the new language.

2 What the laws of physics do not bind

We start with physics not just because the author is a theoretical physicist and has thus some advantage here but mainly to show that physics cannot be blamed for forcing determinism on us. Moreover, we shall observe that there is a lot of liberty in physics and shall be able to study the nature of the liberty in a rigorous way.

In the present section is also an attempt to explain the relevant physics in a way that can also be followed by non physicists. It will therefore be necessarily simplified and many details that are dear to the heart of a physicist will have to be skipped. We will also avoid all technicalities.

2.1 Old but nor dead: Newton mechanics

What is generally known as mechanics is called Newton mechanics here in order to distinguish it from quantum mechanics. The main question of this section is: how much is controlled and ruled by the laws of physics? If we are to understand this more or less clearly, we need to understand the basic common structure of the laws of the theories such as Newton mechanics, quantum mechanics and general relativity. A few abstract and general notions are needed for that: system, dynamical equation, state and space of states.

The system in Newton mechanics consists of particles with given masses. Only after the system is chosen (the number of particles, their masses and interaction with each other and with the outside), the theory give us its dynamical equation, i.e, the law that every motion of the system must fulfil. The law alone however does not determine the motion. To obtain a unique motion, a state of the system must be chosen at a given instant of time, mostly at the beginning of the motion and then evolved by the dynamical equation. The state in Newton theory is constituted by the position, direction of motion and velocity of each particle. All possible states form the so-called space of states.

Let us consider an example. The trajectory of a bullet depends on the position from which it is shot, on the direction of the gun and on the amount of powder loaded. The position can be described by three coordinates (three numbers), the direction by two angles (two numbers) and the amount of powder is tantamount to the velocity of the bullet, which is one number. In this way, six numbers are sufficient to describe the initial state of the bullet. The resulting ballistic curve of the shot is unique in principle. It can be also calculated from the dynamical equation. The bullet is then at some position, it has one direction of motion and some velocity at every time instant after the shot, that is exactly one state. As every state is given by six numbers, the state space can be viewed as the set of all number six-tuples.

This is the general logical structure of the laws. What remains undetermined by the theory? First, the choice of the system does. The choice determines what is the dynamical equation and what is the state space. Then, any state from the state space is freely eligible and the choice makes the motion unique. Isaac Newton was aware of this feature. For instance, the fact that all planets known to his time moved in the same plane around the Sun could not be derived from his equations and he wrote [6]: "Deus corpora singula ita locavit." In our language, God has chosen the initial state.

The freedom in the choice of state is usually understood in a passive sense as the generality of the dynamical equation, that is, its applicability to many different situations that may occur spontaneously in Nature. It seems, however, that one can go a step further and interpret the freedom as an active freedom of physicists. The

assumption can be formulated as follows.

Physicists are free to choose a system from a broad system class and a state of the system from a large part of the corresponding state space. Then, they can set out this system in this state in a laboratory (or elsewhere) at an arbitrary time.

We can call this hypothesis Realizability of Physical States. The liberty that Newton attributed to God in the large is so attributed to physicists in the small. There is a saying that everything not explicitly allowed is forbidden in German-speaking countries while everything not explicitly forbidden is allowed in English-speaking ones. Accordingly, we adopt the Anglo-Saxon standpoint here.

I could not find a direct formulation of the realizability of physical states in the literature. It seems that it is always tacitly assumed in the work of experimental physicists. In any case it is completely compatible with empirical praxis as well as with everyday laboratory work. Generally, this kind of experimental freedom seems even to be one of the basic assumptions of science. As concerns the trajectories of the bullets, the hunters have the experience that they can carry their guns everywhere in order to shoot from there in any direction they like. The hunt would not be much fun else.

One of the basic principles of statistical mechanics can be viewed as a statement about a different kind of liberty. To explain this principle, let us limit ourselves to thin gas in equilibrium. Such a system contains an enormous number of particles. It is practically impossible to determine the state of such a system by some measurements, or to realize a chosen state of it in the lab. The available information about the system includes only values of some overall quantities such as total energy, particle number and volume. There are many states that are compatible with such description. Now, the principle that we are explaining says that all states that are compatible with fixed energy, particle number and volume are equally probable. (The name of this principle is Micro-Canonical Distribution). More precisely, if we set up very many vessels that have the same volume and that contain the same number of gas particles with the same total energy in each vessel, then every allowed state appears with the same frequency. Independently of how the vessels with the gas are manufactured, all of the allowed states are present with the same probability. Thus, we can realize any of them although we do not know and, in fact, cannot find, which. Still, the principle has many interesting consequences and is very useful.

2.2 Rise and fall of determinism

An important feature of Newton mechanics is that the values of all observable mechanical properties of a system are uniquely determined by the state. In our example, the energy, momentum, angular momentum etc. of the bullet to a given time can be calculated from its position, motion direction and velocity at the same time. Assume that the entire world is mechanical, that is, it can be reduced in its entirety to a system of massive particles and forces between them so that all properties of all objects could be calculated from their mechanical properties, then a surprising consequence follows. If the state of the world were known at some time, then everything what can be known about the world at any other time could be calculated in terms of the world dynamical equation. Even if no such complete knowledge or calculation were possible, be it for practical or principal reasons, but if the world were a mechanical system, then it would still follow that everything what ever happens including every detail is predetermined (or post-determined). The only liberty that remained would be the freedom in the choice of an initial state from the (huge) state space of the world. This view of the world is called determinism.

Determinism was popular in the nineteen century because of the great progress then in the project of reducing all physical properties to the purely mechanical ones. For example, temperature can be so explained and calculated, if one assumes that macroscopic bodies consist of invisibly small particles—atoms or molecules—and that these particles move according to mechanical laws. It turns out that the temperature of a body is proportional to the average one-particle energy of its constituent particles. However, in the first quarter of the next century, the more basic quantum theory emerged, and this theory does not support the deterministic view (we shall study quantum theory in the next subsection).

Newton mechanics, if cut down to size, remains valid. If we restrict ourself to systems of macroscopic bodies that are not sensitive to the influence of the quantum micro-world, that move with velocities that are much smaller than the velocity of light, and if the gravitational field is weak then the bodies would move with high precision according to Newton mechanics.

Now, an important aspects of the principle of realizability of physical states from the previous subsection can be explained. There, a real freedom rather than an apparent one has been postulated. This would contradict the validity of Newton mechanics if the principle would concern only mechanical systems. The inclusion of physicists into the formulation of the principle allows us to avoid the paradox, because Newton mechanics cannot be considered as valid for the whole extended system consisting of the original one plus the physicist.

Although the freedom of physics thus concerns the interpretation of some aspect of Newton mechanics, it is primarily a property of living organisms. This, it turn,

cannot be studied by Newton mechanics and we don't understand it yet. It will be studied systematically in Sec. 4.

2.3 What we learn from quantum mechanics

Quantum mechanics has the same basic logical structure as Newton mechanics. Again, there is an affluence of various quantum systems. With each system a dynamical equation and a space of states is associated. Given a state at a time instant, then the state at any other time can be calculated from the dynamical equation and is unique.

And again, the choice of system and state is not restricted by any rule in quantum mechanics, only by practical feasibility. The only difference is that the realizability of physical states is explicitly formulated in some textbooks of quantum mechanics. For example [7], P. 48, contains the realizability as a part of the so-called superposition principle. This may be partially stimulated by the fact that a formulation of quantum mechanics without observers is difficult. Still, the original reason for including physicists into the realizability principle of Newton mechanics need not hold here. If quantum mechanics is applicable to the extended system containing physicists no contradiction has to result.

There are however other important features that make quantum mechanics very different from Newton mechanics. We cannot explain all, but two of them will play an important role later. These are the indistinguishability of quantum systems and the statistical character of quantum mechanics. The first means that quantum systems of the same kind such as all photons, all hydrogen atoms or all molecules with the same compositions are utterly and absolutely equal. Two products of some mass production factory may look equal, but they can be recognized from each other, we can, e.g., make a mark on one, there is no question which of them is here and which is there, etc. This is impossible with quantum systems even to such an extent that any physically sensible state of a system containing two particles of the same kind must be invariant with respect to their exchange. Moreover, there is a relatively small number of different kinds while systems of each kind occur in a huge number. This reducibility of the micro-world to few absolutely equal building blocks has no analogy in the classical world. It will turn out to be important to the biology and to the freedom of living organisms.

The statistical character is not apparent at the level of dynamical equation, which determines the states uniquely and is sometimes classified as deterministic, but is rather associated with the state². Given a state, then there are quantities the

²This is in fact analogous to the statistical mechanics, where states can be identified with distribution functions. The dynamical law is the so-called Liouville equation and it also determines the distribution function at any instant of time uniquely if it is known at one. The values of mea-

measurements of which always give the same value from some set that is called spectrum of the quantities. One says that such a quantity have a sharp value in the state. Most quantities however are said to have no values in the state in spite of their measurability. That is to say, their measurements give different results even if the state on which the measurements are done remains the same. Only the distribution of these results can be calculated from the state, i.e., each value from the spectrum has a fixed probability determined by the state. Let us show typical details by means of an example.

As our system, we choose a single photon. Of course, we can never observe a single photon in the everyday life. What we know as light is always a cloud of a large number of photons. To create a single photon requires a sophisticated technique (which need not be described now). The photon can moreover be created in a state, say, in which its momentum has a sharp value. According to the well-known Heisenberg uncertainty relation, the position of the photon is then totally "unsharp". What does this mean for the measurement of the position?

The spectrum of position is the whole space. We can measure the position from a subset of the spectrum by a photographic plate. The basic property is that a single photon can create only a single black point on the plate if it hits it. Hence, "totally unsharp" cannot mean a large smeared smudge on the plate made by a single photon. Instead, it means that repeated measurements will result in many black points and that the distribution of the points, after very many measurements have been done, is uniform. The following interpretation can, may be, help. The photon in our state does not have any position at all before hitting the plate. The position is "created" only by its interaction with the plate. The interaction cannot be controlled and gives different results in each run. Of course, one cannot readily imagine some object without a position; one of the main principles of some philosophical theories of existence is that existing objects must have positions. However, there is no difficulty for this philosophical principle: one can simply imagine that it is the state of the photon that is smeared throughout the space. An ocean is an object, the position of which is very extended indeed. Only, the physicists prefer to speak of the photon as not having any position to saying that its position is the whole space because the position is a specific well-defined quantity in quantum mechanics and the possible values of this quantity are points (in our language, its spectrum is a set of points).

Generally, quantum experiments look as follows. First, the experiment itself consists of a number of runs. In each run, we obtain a single quantum system (here the photon) from a source, which is some macroscopic apparatus. The source is constructed in such a way that the photon obtained from it in each run is in

surable quantities however are not determined uniquely, only their probabilities can be calculated from the distribution function.

the same quantum state. The (macroscopic) arrangement of the source and the measuring apparatus (here the plate), which is again a macroscopic system, is the same for each run. The runs are performed at different times and have therefore some time order. They can be performed at different places. In each run, we obtain a certain value from the spectrum which can be read off at the measuring apparatus (here, the black points at the plate). If the experiment has sufficiently many runs then the distribution of the values obtained is well approximated by the probabilities that are calculated from the state according to rules of quantum mechanics.

In effect, everything done by an experimentalist is to manipulate and observe some macroscopic devices. The account of the experiment can be completely reduced to description of the behavior of macroscopic objects without omitting anything indispensable for its understanding. It is the macroscopic structure of the source that says the physicist whether it sends out photons or whether it will rather be electrons, as well as what is the state of the particles. And it is a macroscopic change of the measuring apparatus that disclose to him which value of the measured quantity has been found. Hence, the unpredictability is not just hidden in the micro-world without any relation to our macro-world. It is the macroscopic behavior that is not always predictable. More precisely, in the photon experiment, the quantum mechanics does identify a cause for the distribution of the macroscopic black points at the plate. That is because all photons that has been sent have had the state of a sharp momentum. But it does not specify any cause of a particular run giving this particular black point and not another one.

The reader can be embarrassed at the strange dichotomy of micro- and macroscopic that we have assumed in this subsection. This is an old problem of quantum mechanics that is not yet solved completely, but there are some promising ideas [8].

2.4 Causality principle

Causality is an ancient assumption. For instance, Platon's formulation in *Timaeos* is:

Everything that happens must happen because of a cause; for it is impossible that anything comes into being without cause.

However, we have seen that the most basic of physical theory today, the quantum mechanics, keeps silence about causes of something that happens. How can this be explained?

Roughly, there are two possible explanations. The first is to keep the causality principle and to assume that quantum mechanics is incomplete: the causes do exist but are not captured by quantum mechanics. Indeed, the causality principle cannot be falsified: if we do not see the cause of something that happens, then we can

always assume that the cause exists but we do not see it. The second is to accept that the quantum mechanics is complete and to abandon the causality principle: the causes do not exist. This is what most physicists but not all underwrite. For example, Albert Einstein was unable to accept the completeness.

If one accepted the incompleteness then one ought to propose a specific alternative theory, in which the description of states is quantitatively more detailed than in the quantum mechanics. In this way, the causes could be described as differences in the values of some additional parameters, the so-called hidden variables. Such a theory had to be necessarily more involved than quantum mechanics but it must simultaneously reproduce all its measurable results. In spite of great effort of many years, no such theory has been constructed and no empirical support for it has been found.³ Moreover, it has been shown that the hidden variables had to have very strange properties (action at a distance etc.).

Hence, accepting the completeness of the quantum mechanics is more plausible. It does not imply that we have to abandon the causality principle altogether. There certainly are causes for a vast number of events that happen. Everything we need is to modify the principle:

Something that happens must happen because of a cause. The rest of what happens can, however, come into being without a cause so that there is a free choice between possibilities from a specific list. What has a cause, what is free and what are the possibilities lists is regulated.

Let us call this Weak Causality Principle. A model of such a regularity is quantum mechanics. The causes and liberties are strictly regulated so that we always know what is predictable, what is not and what are then the alternative possibilities. More everyday model are the rules of chess. There are some rules according to which the stones must be moved but there is, in every position, more or less freedom in the choice of the move compatible with these rules.

Can the weak causality be included into a coherent picture of the whole world? In particular, is it compatible with the rest of physics? We have seen that what happens within the Newton mechanics satisfies the (strong) causality principle, but we have also mentioned that the validity of the Newton mechanics is limited and this removes possible contradictions. Quantum mechanics, of course, is all right.

³There are deterministic models of some restricted kind (non-relativistic) of quantum mechanics such as the pilot-wave theory. They are, however, not suitable to be extended.

2.5 A subtle change in the interpretation of general relativity

However, there is another modern theory called General Relativity, which describes the world on the large scale. An important theoretical concept of general relativity is that of space-time. This is a four dimensional space so that there are four independent directions at each point, three space-like and one time-like and the space-time includes all space points at all times. The manifold carries the so-called space-time geometry that determines distances and time intervals and it also carries matter. The general structure is similar to that of the Newton theory in that it admits a number of different space-times (=systems), that there are states filling up certain state spaces that are different for different space-times and that there is a dynamical equation.

The global character of general relativity is quite essential if we are to compare it with Newton or quantum mechanics. There does not seem to be much choice of the system now especially when the theory describes the whole world for all times. We can still maintain that the space-times represent different models of the universe. It is, however, difficult to require from physicists to set up an arbitrary state of a whole world in their laboratory at an arbitrary instant of time.

The character of states is different in general relativity in still another way. They are associated with spacelike hypersurfaces in the spacetimes. A hypersurface is a mathematical construction rather than anything real. A space-time can be represented by many different trajectories in the space of states corresponding to different foliations by spacelike hypersurfaces of the space-time.

There is no mark on the space-time that would distinguish the present instant from all the other ones and there is consequently no difference between the structures of past and future. The usual interpretation is to say that this difference is purely subjective and that the present instant can be anywhere depending on where is the observer, while the space-time is considered as an observer-independent description of the total reality. The reality is thus fixed for all times. This deterministic conception of world is called Block Universe by some philosophers [9].

However, the picture of time that follows from the weak causality is dominated by an asymmetry between past and future. The future does not yet exist and more possibilities are still open for it. The past is fixed, in principle, because the choices are done at the present instant. Such an asymmetry is not new in philosophy. Our ideas are similar to Popper's [4]. Thus, the task to make the weak causality compatible with general relativity requires to solve two problems. First, to see if the randomness can be included into the dynamical equation and second, to specify, where do the choices take place.

To prepare the inclusion of the randomness, some words must be said about the

nature of the dynamical equation. Each space-time has two aspects: the space-time geometry and the matter. An essential feature of general relativity is that gravity and space-time geometry are two aspects of one and the same structure. Then, because matter creates and influences the gravity, the space-time geometry must depend on the matter. The equation that couples the matter and the space-time geometry is called the Einstein equation. If the model contains no matter, then the Einstein equation can simultaneously serve as the dynamical equation of gravity.

Now, in constructing a universe model, we are free to choose various kinds of matter and this can also be done in such a way that the evolution of matter depends on some random variables taking values from a set of possibilities⁴. Then, the corresponding dynamical equation will not be deterministic. A state of the universe at one instant of time together with its dynamical equation do not determine its state at the next one unless the next values of the random parameters are chosen. Such a simplified model shows that randomness can in principle be included in general relativity.⁵

However, an instant of time is a space-like hypersurface that can be chosen arbitrarily in the spacetime. If a relativist calculates an evolution, he first chooses an initial hypersurface and, second, he specifies some rule, called gauge choice, of how time is then to proceed along with the evolution of geometry and matter governed by the dynamical equations. It can be proved that the result is independent of the gauge choice. We shall try to require a similar independence in the evolution containing random elements. For that, of course, would be necessary that the choices are the same even if they are done along different spacelike hypersurfaces.

One obvious way to do that is to assume that the choices are made locally. Then, if two hypersurfaces intersect at a point, one can recognize if the choices done along one of them at the point coincide with that done along the other at the same point. Let us call these points, or some smeared version of it, Local Presences. We assume that local presences have an objective, that is observer independent, real existence, that is, things really happen at their time and places. The local presences they are the only source of our evidence about reality.

Some readers could ask, if we are to worry about realism. Is it not already

⁴More precisely, the state equation of the matter contains some parameters such that any time dependence of the parameters is compatible with the Einstein equation, (satisfying certain conservation laws) and can be considered as a part of the evolution. Such a construction can easily be performed for homogeneous and isotropic cosmological models.

⁵It should be mentioned that some models containing classical gravity and quantum matter have been studied thoroughly [10] but then the gravity source has been assumed to be the average value of its quantum behaviour. This is of course only an approximation valid in the cases when the average value describes all quantum possibilities in a sufficiently precise way. (Technically, this means that the mean quadratic deviation is negligible.)

generally accepted that quantum mechanical evidence, especially after Aspect experiments, definitely disproved realism (we use the notion of realism as explained, e.g., by [13])? The answer is that it is not generally accepted and that a lot of research on this problem is being done. We shall try to keep to the old-fashioned realism as long as it will be possible.

From inside our local presence, we can observe what is just happening further away, for example at the Andromeda nebula. What we can see is going on within some local presences there, which have to be arranged along our past light cone and are shifted by some millions of years from our local presence because of the distance and the velocity of light. We still assume that what we observe there are some aspects of an observer independent reality as it was in its time there.

However, what is the past? Clearly, the past exists only as a memory (i.e., a specific arrangement of synaptic strengths in some brain) or other kind of record that an observer, or a family of observers, can make about the observations done within each of their progressing extended presences. Only in this indirect way does the past have to do with reality. (Childhood memories are subjective, the child itself in its time was real.)

The records are analyzed, compared and ordered: processed. This is an important part of the game. Certain entities can be found that seem to be always there (such as space-time events, specific classes of objects and fields). For certain aspects of the entities, temporal and spatial relations seem to be valid, for instance, the arrangement of space-time events into a smooth manifold with some geometry. Some causal relations can be summarized and generalized in the form of evolution laws. Other aspects of the entities can exhibit a kind of liberty. In this way, a picture of some broader space-time structure emerges so that the pasts of different observers can be included into a unique one. The aim is to construct a logically coherent set of explaining and ordering hypotheses from which all evidence can be logically deduced.

The past as a (processed) record seems to be fixed in all aspects and details. There are two very different reasons for that. First, the choice from the alternatives of all liberties has been done and no change is any more possible. Second, we usually suppose that different observations or observations of different observers concerning these already done choices can finally be put into agreement, or that their contradictions can be satisfactorily explained. In particular, any small neighborhood inside of a past describes what happened when it was a presence and it can be considered as a local presence of any observer being then in it, and the assumption is that his observations within this local presence will not in principle contradict ours. This is a rather non trivial hypothesis on which, in fact, all of the science is based; it has a natural explanation in the philosophical realism. We call this

hypothesis The Uniqueness of History.

Finally, what is the future? The very existence of future is a hypothesis based on the analysis of the records which confirm that, as yet, the presences have always progressed. Similarly, we can extrapolate the existence of the entities and the validity of the laws to where we cannot make direct observations, in particular into the future of each respective cone. Only in this way, we can make predictions. On the other hand, the predictions can concern always only a part of the future. As we have seen, there are also unpredictable aspects. Thus, some part of the world is newly created ("chosen by Nature" under more possibilities, cf. [4]) at the presences, another part is determined by the past.

The ideas described up to now are also supported by the contemporary knowledge of how brain neocortex works, even in mice. It constructs a structured, i.e., already processed, memory record of all experienced (interesting aspects of) presences and uses this material to create expectations (cf. [14]). Similarly, the human science is being made, at least in principle and in rough features, analogously, leading from records to predictions, too. The nature of scientific reasoning is described in [11]. We can say pointedly: What really exists are only the local presences. The past as well as the future are nothing but products of neocortex.

Now, we can answer the question of how the space-times of general relativity are to be interpreted: The space-time must be just a hypothetical past, that is, the unique history of an evolution assumed to be completed (cf. [12]). With other words, a spacetime can be viewed as one possibility of the Liberty of Universe, which is the union of all liberties. The problem of asymmetry between future and past does not even arise because we are considering only the pasts.

The above is only a subtle reinterpretation of general relativity because it does not seem to lead to changes in any calculation and any discussion concerning measurable properties within general relativity and with the Einstein equation done as yet. The reason is, that such calculations and discussions can primarily apply only to past evidence and hypotheses formed primarily about the past, as it has been explained above. If we accept this change in interpretation of general relativity, then the weak causality principle becomes compatible with the whole of the contemporary physics.

3 How liberty can be defined

The discussion of the foregoing section has already suggested the conception of liberty as a choice among different possibilities that is compatible with the laws of physics. To see the existence of such a liberty is still not easy because of what we have called the uniqueness of history. The records of the past are unique and hence there does not seem to be any freedom. Even if there is such a freedom, the

possibilities have already been chosen and the history cannot be changed. How did we come to think that there is any freedom?

Recall how the described experiment revealed the liberty in the position of the photon. The experiment consisted of many runs performed at different times, each of them giving a different result. The conditions of each run were specified so that the experimentalist could say: Each run started under the same relevant conditions. This is the crucial point. Apparently, the time and location of the run does not belong to the relevant conditions. Then, it becomes meaningful to say that the same experiment is repeated and that it gives the same or different result as a previous one. This motivates the following definition:

The liberty of a system is associated with certain reproducible conditions and it is defined as the list of different possibilities that are open to the system under the conditions.

The important words "system", "reproducible conditions" and "possibilities" have here a more general meaning than in the photon experiment and are explained below.

The two words "liberty" and "freedom" will distinguish two different concepts in what follows. The liberty as defined above is a relatively simple notion that can be applied even to photons. The freedom will be applicable to living organisms and will denote the fact that the organisms are equipped with the structures, mechanisms and methods that enable them to utilize liberties ⁶.

The term "system" need not be a simple physical system such as a photon or a bullet, but can denote more complex objects such as living organisms. The specification of the object that appears as the system in the definition can be a part of the relevant conditions. This has been the case in the photon experiment, where the nature of the source has constituted a part of the conditions and guaranteed also that what has been sent out was a photon.

The term "reproducible conditions" expresses the main idea of our definition. A liberty is always understood in connection to certain conditions. In principle, broader or narrower conditions allow more or less liberty. However, the choice of conditions is not arbitrary. We assume that the same set of conditions is often fulfilled in different cases, may this happen spontaneously in Nature or may it be sufficiently easy to be arranged by people. A complete list and a clear description of the relevant conditions must enable the check whether the same conditions are satisfied in different cases or not. The reproducibility is the property that makes the liberties empirically manageable and theoretically derivable, similarly as the laws of Nature are.

⁶Thus, the meaning of both words is appreciably extended in comparison with their current use. I apologize for this violence, but I could not find better words and shall accept any better proposal.

The "possibility" ought to really exist as opposed to a purely thought one, in the sense that its realization can be observed at least in some cases in which the conditions are satisfied. It can be an effect of a cause that lies outside the condition set so that some of the possibilities has its own cause in a given case. It can as well be that for its particular realization no cause can be found and even need not exist, such as it has been assumed in quantum mechanics and stated by the weak causality principle. Or there can be a mixture of chances with causes. Our definition of liberty is such that it does not include the way in which its possibilities are realized. It may go in a random way by a chance or in a deterministic way by a cause. The same possibility of a given liberty can be realized in different ways in different cases. We shall see complex examples with a lot of interesting structure later.

The number or some other measure of the amount of all possibilities can even serve as a numerical value of liberty. For example, if there are N different possibilities, we can define $\ln N$ to be the value of the liberty.⁷

Let us recall some examples from the physics section. The conditions of the liberty observed in the photon experiment are that the nature of the source is to send out photons in the state of sharp momentum, second, that the measurement apparatus is a photographic plate of certain kind and third, that the devices are arranged in a fixed way. All conditions concern only macroscopic properties of the devices, but the standard interpretation of quantum mechanics considers them as maximally narrow: no further conditions exist that would be relevant. That is; other possible accompanying circumstances such as e.g., the time and location of the measurement, the conjunction of planets and stars, the mood of the boss, the state of the stock exchange, etc. can indeed be shown to have no observable influence on the course and results of the experiment. The possibilities are the points at the plate that can become black. These are all points of the plate, forming in this way a well defined list of possibilities. The liberty could be measured, e.g., by the logarithm of the area of the plate.

Some liberties are important and useful even if their conditions do not form a maximally narrow sets. That is, further conditions could be added, at least in principle, so that the number of possibilities will decrease. Such liberties do not logically contradict the (strong) principle of causality or the determinism. The statistical physics of thin gases in equilibrium yields an example. The conditions are that the total energy, the total volume and the total number of molecules in the vessel have certain values at certain time t . Such conditions are compatible with a huge number of mechanical states of the gas molecules at t . The number of possibilities equals the number of possible states. If any such state really occur at t then there can be a cause of it in the past to t that has nothing to do with

⁷If each possibility has its own probability, then the Shannon formula for entropy could be used.

the conditions. These conditions could in principle be narrowed so that just one arbitrary fixed mechanical state would be allowed at the time t . Then, there would be only one possibility.

Another liberty of such a kind is connected with the so-called emergent phenomena. These are properties of complex systems that cannot be derived exclusively from the properties of its individual constituents. One can also say that the whole is greater than the sum of its parts. The simplest example are two electrons, two protons and two neutrons. They can form either an atom of helium or two deuterons so that we cannot say what are the properties of the composition if no additional information about the structure is available. The reason is that there are two possibilities of how the constituents may combine. The possibilities constitute a liberty that we can call *liberty of combination*. We can generalize it by counting also the numbers to the possibilities. Then, the three kinds of constituent above can combine into about one hundred stable atoms and these atoms can combine into zillions of stable molecules, crystals and mixtures. This is a huge liberty, which underlies the surprising wealth of structures in Nature.

4 How living organisms take advantage of liberties

The limited knowledge of the author in the fields of biology, ethology and brain research may make the following deliberations somewhat uncertain. He apologizes for irritating inaccuracies that a specialist surely would find if any happened to read this section. Still, it seems that the main idea ought not to be completely wrong in particular also because it is little more than a reformulation of Darwinism built on the notion of liberty. We shall see how this notion can throw some fresh light on a number of facts of life.

4.1 Liberty of mutation

Let us start by a short story about how a species of bacteria called *staphylococcus aureus* develops a resistance to a new antibiotic. The antibiotic reacts with a molecule of the bacterium cell in such a way that some life process is disturbed. Thus, this molecule ought to be changed so that it does not react lethally with the antibiotic any more. Of course, the structure of the cell must be sufficiently flexible so that all life processes can also run with the new molecule. Let us call mutations all changes that satisfy the second condition. The allowed mutations can be considered as the possibilities of a liberty. We call it the liberty of mutation. All

conditions of this liberty is just the ability to live of the mutated staphylococcus cell. The resistance can develop only if the liberty of mutation is sufficiently large.

How do mutations come about in the first place? It seems that this is more or less random process that works all time and that has no plan or aim. Bombardment by some radiation such as cosmic rays, disturbance by some contingent chemistry and physics, or even some contact with other bacteria and viruses can be effective. Mutations occur with single molecules and it seems that quantum mechanics is important for them. In any case, there is enough space for randomness. It is true that the occurrence of the mutation protecting the bacterium from the antibiotic has non-zero but very low probability. However, there is a very large number of staphylococcus around. This number multiplies the probability, making the favorable mutation feasible.

The cell with the mutation must be there before the antibiotic is applied. The antibiotic then kills all cells except for those that exhibit the advantageous mutation. We can say that the antibiotic makes a selection, a choice among the possibilities of the liberty.

Finally, the trick must be remembered in some way so that it can be applied against each future antibiotic attack. The mechanism working in bacteria is the following. Every cell has a genetic blueprint, written down in a particular molecule of deoxyribonucleic acid (DNA). The mutation must first appear in the molecule of DNA of a parent cell, and only then, as the result of the cell division, it is referred to the molecule that reacts with the antibiotic in a daughter cell. That is because the new blueprint is used for the construction of new cells in the process of cell division. Each of them also inherits a copy of the blueprint. In this way, the mutation is completed, remembered and proliferated.

DNA is a chain of four kinds of building blocks, the nucleotides. The ability of DNA to carry information is based on the indistinguishability of different nucleotides of the same kind and so on quantum mechanics. The most important property is that the sequence of nucleotides can be arbitrary. Each sequence, of any length and order, can be joined into a stable molecule of DNA. This is a kind of chemical liberty with the possibilities being the different sequences, and it is restricted only by the problem of keeping very long chains undisturbed and accessible.

We can identify three essential processes in how living organisms utilize liberties. First, there must be a real liberty in our sense, that is, its conditions are fulfilled sufficiently often and all its possibilities can really occur or, they can be realized; we call this process realization. The possibilities are realized in processes including pure chance, contingency as well as causal laws. The liberty must be sufficiently large to contain some advantageous possibilities. Second, the choice between the possibilities must be done so that the advantageous one prevails; we call this process selection.

Third, the advantageous possibility must be remembered for future use; we call this process memory. Realization, selection and memory are very general processes that always constitute the strategy of living organisms with respect to liberties. More exactly:

A Freedom is the ability of living organisms to carry out the processes of realization, selection and use of memory with respect to a liberty.

An example of how the realizability concerning the mutation liberty can be improved in complexer organisms than bacteria is the phenomenon of sex. The claim that sex would enhance human liberty may seem preposterous. However, we have in mind the liberty of mutation rather than the freedom of will.

Let us give a simplified introduction to sex phenomenon that will be sufficient for understanding which liberty is improved by sex and how it works. We will draw upon [15] to a large extent. First, within the whole genetic material of an organism, its DNA, shorter pieces called genes can be found each of which code for some property, such as the color of eyes, say. Within all individuals of a fixed species, more genes with the same function but different results can be found. In this way, more genes, like the brown eye and the blue eye gene, are rivals for the same slot on the DNA; such rivals are called alleles. The origin of the alleles lies in a step by step mutations occurring in different lineages. There is a sense in which the genes of the population including all alleles resulting in this way can be regarded as a gene pool. The population is constituted by all contemporary individuals of a species. In this sense, the pool is a propriety of a species at a given time.

Now, there are many ways in which a possible gene combinations forming a whole DNA molecule that would encode for a viable individual could in principle be chosen from the pool. All these combination possibilities form a part of what we have called the liberty of mutation. But could such combinations come about in a reasonable time? It turns out that the phenomenon of sex does just that.

Each cells of an individual contains the blueprint for the whole body, not only for the cell itself. In the species that can reproduce sexually, most cells of an individual contain exactly two copies of it, one from the father and one from the mother of the individual. Only the sexual cells of the individual, eggs or sperms, contain just one copy. During the manufacture of these cells, some bits of each parental DNA physically detach themselves and change places with exactly corresponding bits of maternal DNA. The process of swapping bits of DNA is called crossing-over. It seems that the choice of the points on the DNA where the pieces have their ends is random. It is, moreover, different in each sexual cell of the same individual. The density of the points at which the DNA is broken by crossing-over is sufficiently large for something to happen at all and sufficiently small so that there is a large probability for clusters of several genes to stay together and to be copied truly.

Because of sex and crossing-over the gene pool is kept well stirred, and the genes partially shuffled. Thus, the realization of very different possibilities of mutation liberty is accelerated so that the incidence of bold changes is strongly enhanced. In the whole process starting from the choice of sexual partner through the crossing-over in each sexual cell to the combination of a sperm with an egg, something is subject to causal laws but a lot is purely accidental. This is often so with the realizability.

The selection mechanism works only on the level of individuals because it is driven by the success or failure of whole individuals. This means that the selection does not act on the genes directly. As far as a gene is concerned, its alleles are its deadly rivals, but other genes are just a part of its environment. The effect of the gene depends on its environment. Sometimes a gene has one effect in the presence of a particular other gene, and a completely different effect in the presence of another set of companion genes.

The memory that would be necessary to remember the best combinations of alleles is worsened by the sex. The necessary random break up of the whole combination comes about independently of how advantageous the DNA of the mother or of the father has been. Only those pieces of DNA can be copied truly that are short enough so that their break up during crossing-overs has a very low probability. These can be clusters of just a relatively small number of genes. That is why single genes or relatively small clusters of genes are units of heredity in the sexually reproducing organisms rather than the whole DNA as in bacteria.

Hence, the long-term consequence of non-random individual death and reproductive success are manifested in the form of changing gene frequencies in the gene pool. Evolution is the process by which some genes become more numerous and the others less numerous. On one hand, sex greatly improves the realizations, on the other, it subtly impairs the memory. Sex is a delicate phenomenon.

4.2 The liberty of motion

Some multicellular organisms such as animals possess an additional liberty that we shall call liberty of motion. This means that parts of animal body, e.g., trunks, legs or wings, can take different relative positions to each other without inhibiting other functions of the body. The change of this relative position, if there are no external hindrances, can be carried out with various velocities and external bodies can be shifted thereby with various forces. This defines a list of possibilities—the liberty—that can in principle be realized by each individual body. Plants can also perform limited motions and have some choice, for instance between different possibilities of growing, but these are not included in our definition.

It seems that animal motions are always organized with the help of some nervous

system. Experiments show that certain nerve signals trigger certain motions. "Useful" sequences of motions such as running or flying are carried out by specialized sets of nerves connected in a particular way. Moreover, some influence of sense data on motions are made possible by other connections of nerves. The influence can be direct so that some stimulus elicits some motion, or modulatory so that some stimulus modulates the strength of some direct connection.

The wiring of the nervous system—which neuron is connected to which—is inherited and fixed. However, the strength of some part of the connections is variable. There is a liberty called synaptic plasticity [16]. Its possibilities are different strength of the connections. There is a certain threshold so that the connection is broken, if the strength falls under it etc. The animal can start with arbitrary strengths; the starting strengths contain an some space for randomness. The choice from the list of possibilities is causal, certain choices following certain stimuli or (time-ordered) sets of stimuli. Such changes in the synaptic strengths can last several minutes, which constitutes a short-term memory, or for weeks or years, the long-term memory. The process is called learning. Many examples of learning starting with invertebrates are can be found in [16].

The learning has some limitations, because many connections are fixed. An example thereof is the experiment with the insect species *sphex ichneumoneus* as described by Dennett [3], P. 82:

When the time comes for egg laying, the wasp *Sphex* builds a burrow for the purpose and seeks out a cricket which she stings in such a way as to paralyze but not kill it. She drags the cricket into the burrow, lays her eggs alongside, closes the burrow, then flies away, never to return. In due course, the eggs hatch and the wasp grubs feed of the paralyzed cricket, which has not decayed, having been kept in the wasp equivalent of deep freeze. To the human mind, such an elaborately organized and seemingly purposeful routine conveys a convincing flavor of logic and thoughtfulness—until more details are examined. For example, the wasp's routine is to bring the paralyzed cricket to the burrow, leave it on the threshold, go inside to see that all is well, emerge, and then drag the cricket in. If the cricket is moved a few inches away while the wasp is inside making her preliminary inspection, the wasp, on emerging from the burrow, will bring the cricket back to the threshold, but not inside, and will then repeat the preparatory procedure of entering the burrow to see that everything is all right. If again the cricket is removed a few inches while the wasp is inside, once again she will move the cricket up to the threshold and re-enter the burrow for a final check. The wasp never thinks of pulling the cricket straight in. On one occasion this procedure

was repeated forty times, always with the same result.

What appears here as a lack of freedom is in fact a lack of the freedom precisely in our sense: some connections cannot be changed.

4.3 Liberty of portable neural representatives

There are processes in nervous systems that are based on learning but are more complicated than it. The existence of such processes in nervous system of invertebrates are suggested e.g. by experiments by Jim Gould with honeybees. The following description is borrowed from [17].

The bees seem to remember some aspects of the environment of their hive and are also able to describe routes within this environment to each other by a kind of body language, the so-called dance.

...finding food depends less on luck and more on sampling from relatively well known foraging sites, areas where food availability depends on seasonal variation in pollen. When a honeybee forager returns and dances, other hive mates pay attention. Depending on information in the dance and the current needs of the hive with respect to finding food as opposed to storing it, the observers will either stay put or go out on their own foraging expedition. The observer must therefore process the information in the dance and then place it within a system of spatial representation...

...Gould observed a hive that has been maintained near a lake for a long period of time. This provided some insurance that the honeybees were familiar with the local environment. Each day, one group of foragers was trained to move from a release spot away from the hive to a boat on land, stashed with nectar; once they loaded up on a meal, they were captured and prevented from returning to the hive. Over the course of several days, the boat was displaced further and further from the release site until one day it was square in the middle of the lake. At this point, the foragers were allowed to collect nectar from the boat and then return home. When the foragers arrived at the hive, they danced, indicating the location of the nectar-laden boat. Although the hive paid attention to the dance, virtually no one flew out of the hive. Gould suggests that the honeybees responded to the forager's dance by referencing their cognitive map. As for this colony, the map fails to reveal a "Food Here" sign in the middle of the lake. Sceptical of the dancer's message, hive members wait for a more reliable dancer. (PP. 77-78.)

The information about the environment is represented and stored in the honeybee nervous system forming thus a real entity different from the environment itself. It has to be created during the life of individual honeybees rather than built in from the inherited DNA (to build it into the DNA would require thousands of years): it has been learned. In Gould's experiment, some neural representative of the position of, or the way to, the food source forms in the forager honeybee nervous system from the sensory data and its own motions during the flight; it is also learned. The dance reexpresses it as a sequence of motions that can be "understood" by the hive mates. That is, observing the dance they can build, learned in this way, a representative of the food way in their nervous systems.

The representatives of sensory data, of motion sequences and of environments concerning Gould's honeybees are examples of what we shall call portable neural representative, (PNR). It is a neural representative formed during the life of an individual and the nervous system is able to work directly with these representatives; the word "portable" is to distinguish it from the fixed neural representatives of, say, sequences of motions that have been inherited. Any PNR must clearly be based on some arrangement of synaptic strengths in a specific set of neurons, which are not known in detail. The existence of such a representative is just inferred from behaviour. The name "portable neural representative" reminds of what is really known now. It is, however, sufficiently general, it leaves many details open, and is thus suitable for our purposes.

The bee nervous system is then apparently able to compare the message PNR with the PNR of the environment in order to see whether one is to stay put or to fly out. These and other PNR (such as concerning some work in the hive) are apparently used in the process of selecting the motion sequences before any actual motions are done. The chosen motion is not just a learned specific response to a specific cue. There never has been such a dance before!

Important observable data in this experiment are the numbers of bees that fly out and that do other motions. The relative numbers differ from case to case. The bees themselves are identical clones from the point of view of heredity. This suggests that the different decisions must be due to different PNR to start with. If so, there may also be some random factor.

More numerous and more convincing are experiments with mammals showing similar or more flexible use of memory for choices of motion [16]. The honeybees are much more primitive, in particular they do not possess any hippocampus. There is some discussion about interpretation of Gould's experiments [17]. However, for the thesis of the present subsection, Gould's experiments are not vital.

What is the relevant liberty? The ability of nervous systems to form in principle more or less arbitrary PNR without disturbing the function of the system is similar

to the liberties of mutation or motion and we call it liberty of portable neural representative. It is apparently based on the synaptic plasticity. However, some more specific account of this liberty similar to the previous two is difficult because little is known about the actual structure of PNR in nervous systems. Neural network models of nervous systems might probably be used to get some insight. In any case, this part of Sec. 4 is more hypothetical than the previous one.

This experiment shows how the memory enters the process at many points, we can also find a well-defined selection, but we have only a nebulous idea of how the realization of the possibilities and how the selection proceed within the individual nervous system.

After the choice of a PNR for going out or staying put, the nervous system brings about an actual sequence of motions compatible with it. Thus, the liberty of PNR is associated with the liberty of motion in a similar way as the liberty of mutation is, but it constitutes a distinctly different kind of liberty. By it, the choice procedure is shortened from the time interval covering many generations to a time interval shorter than one individual life. In such a way, the nervous system that might originally just serve to organize motions into suitable sequences becomes the most powerful instrument for utilizing liberties by living organisms.

4.4 The freedom of will

The freedom of will is usually understood as the freedom to select in mind consciously an idea of an action and then to carry out the action. The action can be a sequence of motions, but it also can be another conscious mental action. The consciousness component distinguishes this freedom from the others. We assume that every idea has a portable neural representative and that it is conscious. Then we can effectively restrict ourselves to PNR and the liberty underlying the freedom of will is again the liberty of PNR .

What is exactly the consciousness, in particular, how it is represented by any nervous processes in the brain, seem to be not known. However, some phenomenological understanding is possible and it will be sufficient for our purposes. This means that whether or not anything is conscious for a person must be decided or reported by the person [18]. Of course, recent findings support strongly the idea that unconscious processes are very important and ubiquitous in all cerebral activities. Accordingly, the role of the freedom of will must be smaller than some people would like to think. But we are going to argue that the existence of a kind of this freedom can be assumed without problems.

To begin with, it may be interesting to observe that consciousness has a strong memory component. Not only is one aware of something (that is, conscious of it), but one must also be aware of what one was aware of in the past, so that the well

known roughly continuous, time ordered, stream of consciousness results. This so called declarative memory is heavily used by consciousness all the time.⁸

The crucial hypothesis of this subsection says that the consciousness is a tool that enables one to better use one's liberty of PNR because it is essentially an instrument for complicated symbol manipulations or scenario runnings as well as for the utilization of such calculation results for the choice of actions. The unconscious brain is usually not able to do such calculations alone because it has originally had a different purpose and this may partially explain that all conscious thinking is rather awkward, energetically expensive and relatively slow.⁹

It is interesting that digital computers are also tools to make complicated calculations. Thus, the consciousness can be understood as a method by which we make our brain emulate a digital computer. This aspect of consciousness is well-known and a relatively simple one. It is central for the understanding of the freedom of will that will be put forward in this paper. We can leave the question open, whether or not the consciousness is, at least in main features, reducible to this aspect.

This is not to say that brain solves complicated mathematical problems in the same way as a computer would do. Actually, we do not maintain that unconscious processes are excluded from the whole solution process. Just the opposite is well known to be true. However, conscious processes are necessary at some stages similarly as computers are needed at some stages of modern research projects.

4.4.1 The experiments by Libet

Our hypothesis has several agreeable properties. One of them is that it gives a nice and unexpected interpretation to the celebrated experiments by Benjamin Libet [18]. Libet's experiments are ingenious and very enlightening for everybody studying consciousness, but we shall not accept all Libet's interpretations. A short account of relevant material that will be sufficient for our purposes can be found in the Foreword to [18]:

Libet's work has focused on temporal relations between neural events and experience. He is famous in part for discovering that we unconsciously decide to act well before we think we've made the decision to act. ... Libet asked people to move their wrist at a time of their choosing. The participants were asked to look at moving dot that indicated the time, and note the precise time when they decided to flex their wrist. The participants reported having the intention about 200 milliseconds

⁸However, the process of getting directly aware of something is known to be independent from the process of storing it in the memory.

⁹The consciousness may be slow for other reasons, too [18].

before they actually began to move. Libet also measured the "readiness potential" in the brain, which is revealed by activity recorded from the supplementary motor area of the brain (which is involved in controlling movements). This readiness potential occurred some 550 milliseconds before the action began. The brain events that produced the movement thus occurred about 350 milliseconds before the participant was aware of having made the decision. Libet shows that this disparity is not simply due to extra time required to note and report the time.

Let us compare the experiment by Gould with that by Libet. In both cases, it is the nervous system that selects some PNR and starts the action. In both, the liberty of PNR and of motion is utilized. The two freedoms seem to be of the same.

From the evolutionary (that is, natural selection) point of view, the conscious component in selecting PNR carries with it both advantages and disadvantages. On one hand, it enables complicated deliberations and calculations, on the other, it consumes a lot of energy and time. Now, if we look at the action asked for in Libet's experiment, it itself does not require any calculations, it is a simple choice of time instant. Still, consciousness has been used by the participants before the experiment in order to understand the task, to reduce it to the simple choice of time instant and to prepare it thus for the performance. Then, when the experiment is running, it seems natural that the unconscious brain does not switch in the consciousness because no complicated scenarios are to be elaborated. It is satisfied, after it has done the work itself, with merely dropping a notice to the consciousness to enable a possible veto, and to the consciousness journal (declarative memory) to save this information for possible later use. It seems that the consciousness is not the master but a servant.

Our conclusion from Libet's experiments is therefore different from that of relatively many philosophers or natural scientist. They seem to find there a strong suggestion, or even a proof, that there is no freedom whatsoever and that one's impression of having some is just an illusion. We want to maintain that there is a lot of freedom, even, say, for the honeybees and that human freedom is even larger because people can find more possibilities for PNR with the help of conscious calculations. In our language, the realizability is enhanced. In effect, we do assume that freedom is not an illusion, but we give the consciousness a smaller role in it.

4.4.2 An example: playing chess

Playing chess is an activity that clearly shows the value of conscious calculations. There is a well defined liberty: all moves that are allowed by the rules of the game in a given position. Moves are understood as ideas, not as actual motions of the

stones (a move is a whole class of such motions), and we again assume that each move is some conscious PNR.

As a beginner, one is happy to do the first move which pops into one's consciousness in each position and looks promising, but that leads mostly to a disaster. What is to do is to consciously calculate developments to which such an idea would lead without carrying out the moves on the chessboard; a number of such developments quickly grows if the analysis is extended to the depth of three or more moves and the situation becomes rather messy. Thus, it is no miracle that many digital computers play chess better than most people.

The selection between possible moves is done according to the purpose that one is following. Even if one just wants to win, one's choices might be different in the same positions because of changing skills or because one adapts the choice to one's knowledge of one's opponent. It is also conceivable that one does not need to win. For example, one would like to teach one's child to play the game, etc. In any case, there is a reason for one's choice and we can say that each move that is actually performed by a given player has a cause within the player, at least in regular circumstances.

This idea is rather similar to the philosophy of compatibilism, which attempted to make freedom of will compatible with determinism (see, e.g., [3]). Although we have rejected determinism, this particular idea of compatibilism is fully taken over here. Hence, the essence of our freedom is not in the randomness of our moves. Of course, we can decide to make our moves with the help of dices, but this possibility does not exhaust the concept of our freedom. We agree with the compatibilists that the player is the cause of the player's moves but we do not follow them further in excluding that the corresponding causal chain has started within the player.

It is only when we are getting at a sufficiently large pool of trial moves from which the actual move is to be selected where the randomness often plays a role. The problem is that the computer of our consciousness is not able to do a systematic analysis even in chess. (Today's digital computer cannot calculate the game all the way to the end, either.) We are therefore looking for some move that is motivated by some properties of the position over which we are sitting. Different moves occur to us in a way that is not completely systematic. Trying to calculate possible consequences of each, we learn more about the position so that after rejecting one idea, we are likely to get another, etc.; it is the method of trial and error (cf. [5]). work need not obey any overall algorithm. Algorithmic calculations of our conscious mind's are mixed with some input of the unconscious brain. Even if the unconscious brain does not calculate, it often provides surprising associations of ideas, which themselves may but need not have been obtained by calculation. It seems that the way we

arrive at the trial moves does not form a strictly causal chain¹⁰. In spite of the unconscious component of getting trial ideas, the definitive move selection is, as a rule, conscious and it is indeed the cause of the move that is actually carried out.

The final point is that after calculating through the scenarios and choosing among them consciously, the act of actually moving the stone may contain unconscious elements. The choice exactly when, how rapidly and along which trajectory the move is to be done can be, and mostly is, done without any consciousness. However, this is another liberty. The liberty of the choice between possible chess moves is used with the help of the conscious calculator. The choice between possible stone moves compatible with a given chess move is a different one, which is not relevant to our problem. The question if the conscious mind directly moves the body hand seems to be less important than whether the body hand moves in accordance with the mind plan or not.

The game of chess is, of course, a strongly simplified model of life. It provides, however, all the relevant features of conscious decisions and gives thus an example that fits the above definition of the free will.

To summarize, the notion of freedom that is defined here is not an illusion. Still, it is a more complicated phenomenon than is usually assumed. The whole concept of freedom of living organisms must be separated into several different notions. First, a kind of relevant liberty must be identified, e.g. the liberty of motion. This is a relatively simple concept that can be described in precise terms and that can be studied experimentally. Second, there are ways and methods of how organisms make use of the liberty. For this an involved, many levels (DNA, nervous and locomotive systems) structure evolved which supports both random (in realizations) and causal processes (in selections) and includes a relatively large memory. The way it works is again accessible by experimental study.

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¹⁰There is some analogy here to the way the mutation liberty is used by bacteria: the trial ideas are similar to mutations that come about in a partially random way and the selection in both cases is causal.

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